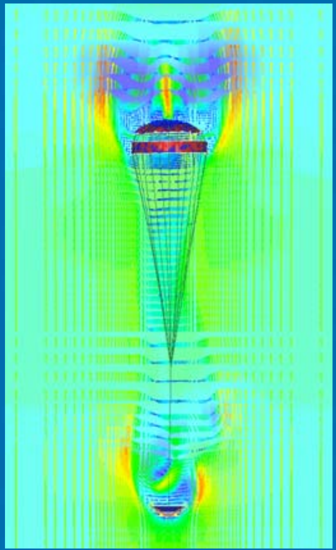
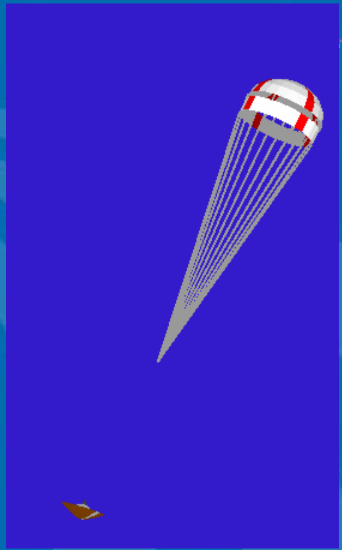


Parachute Seminar



3rd International Planetary Probe Workshop

Parachute Definitions, Nomenclature, and Types

Vance L. Behr

&

Steve Lingard

Vorticity

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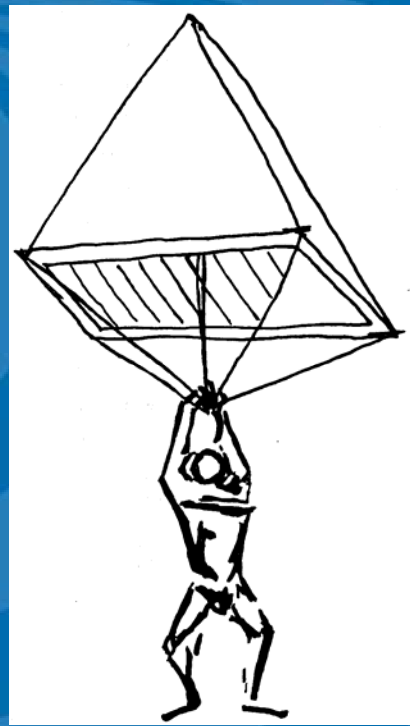
History

- First recorded history in Chinese archives of 12th century
- Da Vinci's sketches in 1514
- Fauste Veranzio claims to have jumped from tower in 1595
- Jean Pierre Blanchard emergency use of parachute in 1784
- Military interest begins c1920
- Parachute delivery of troops and equipment by Germany and Russia by 1930
- High speed parachutes developed since 1930
- Parafoils introduced in 1970's



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Definitions

- **Parachute** - 1) a folding umbrella-shaped device of light fabric used esp. for making a safe descent from an airplane, 2) PATAGIUM, 3) a device suggestive of a parachute in form, use, or operation.
- **Pilot Parachute** - a small parachute which is attached to a deployment bag or the vent of a larger parachute and is used to provide the force required to deploy a larger parachute.
- **Drogue Parachute** - a parachute which is attached to the payload and is used to provide stabilization or initial deceleration or both. Usually implies a larger parachute will be deployed later in the event sequence. Frequently used as the pilot parachute for the main parachute.

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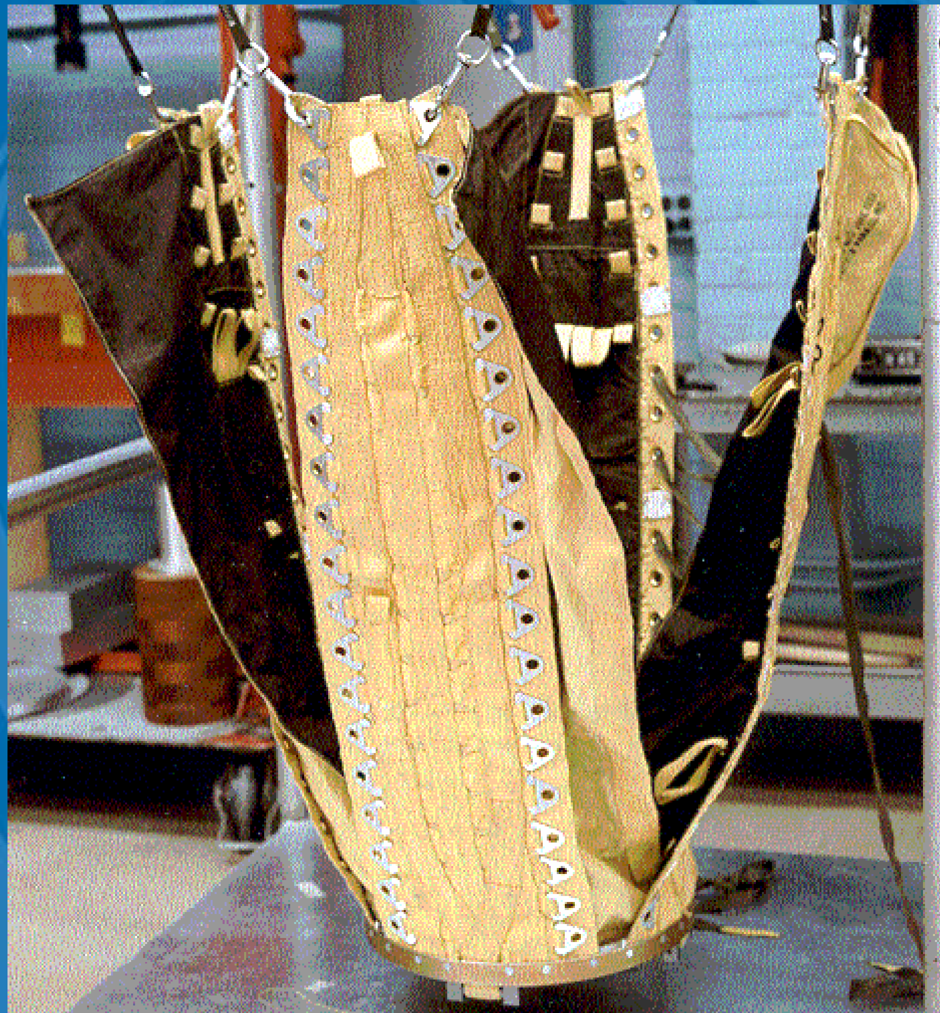
Definitions (continued)

- **Deployment Bag** - a textile container for a parachute from which the parachute deploys.



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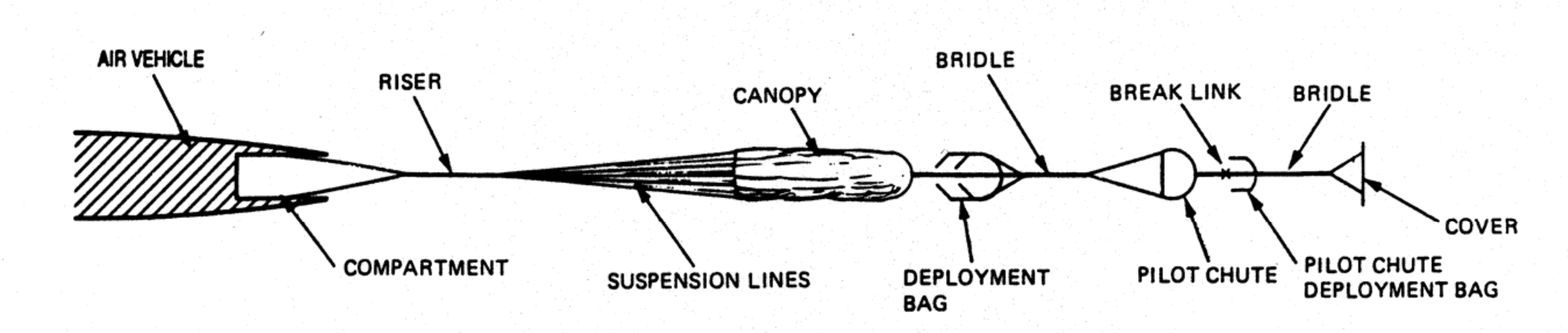
Definitions (continued)

- **Riser** - a line connecting a parachute to its payload. May utilize a single or multi-point attachment scheme. (In some applications referred to as a Tow Line.)
- **Bridle** - a means of providing a multi-point connection to a deployment bag or vehicle from a parachute or riser. (On a deployment bag sometimes called "bag handles".)



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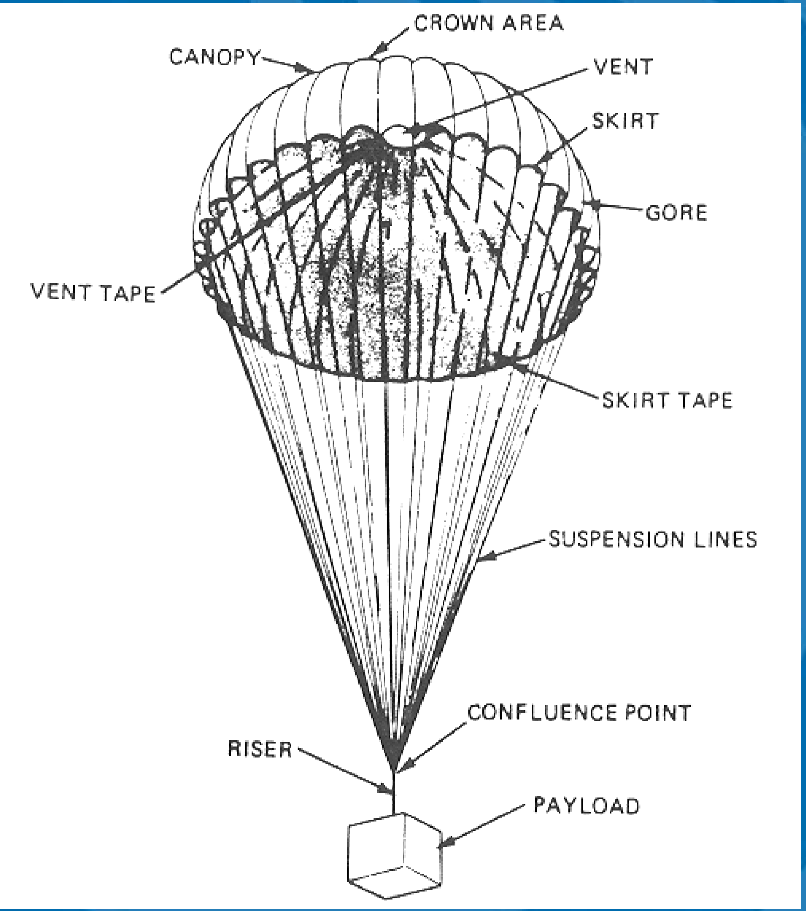
Definitions (continued)

- **Canopy** - the major drag producing element of the parachute.
- **Vent** - open region at apex of canopy.
- **Suspension Lines** - load bearing members extending from the canopy to the payload.
- **Radials** - load bearing member running from the suspension lines at the skirt to the vent lines.
  Gore - section of a parachute canopy between two radials.



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Definitions (continued)

- **Line Stretch** - when all bridles, risers, and suspension lines are "straight" between the payload and the deployment bag and the skirt of the parachute is beginning to be accelerated to the payload velocity.
- **Canopy Stretch** - when the canopy is stretched straight behind the vehicle and ready to start the deployment process. (Occurs after line stretch.)

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Definitions (continued)

- **Snatch Force** - the force required to accelerate a concentrated mass in a parachute system (e.g. the skirt mass) to payload velocity.
- **Opening Force** - the maximum drag force developed by the parachute during the inflation process.
- **Over-inflation** - The period in inflation where the canopy inflates to larger than its quasi-steady full open shape to the dynamics of the opening process.

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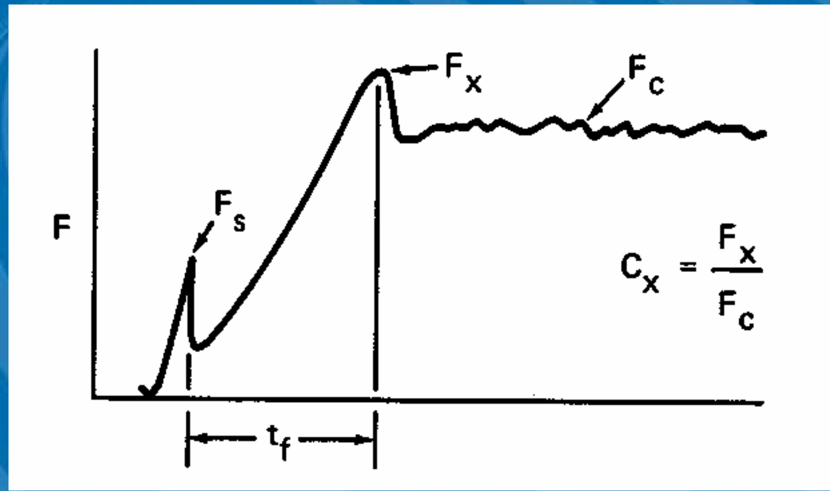
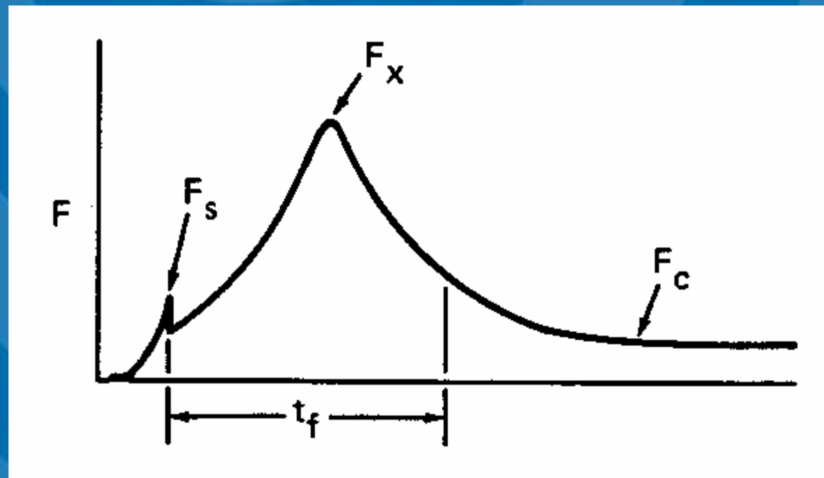
Definitions (continued)

- Infinite Mass Inflation (Wind Tunnel)



Finite Mass Inflation (Most Real Applications)



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Definitions (continued)

- **Wake Re-contact** - a phenomenon encountered when parachutes produce very rapid decelerations of payloads allowing the previously generated wake of air to overrun the inflated parachute thereby temporarily collapsing the canopy and reducing the drag to some degree.

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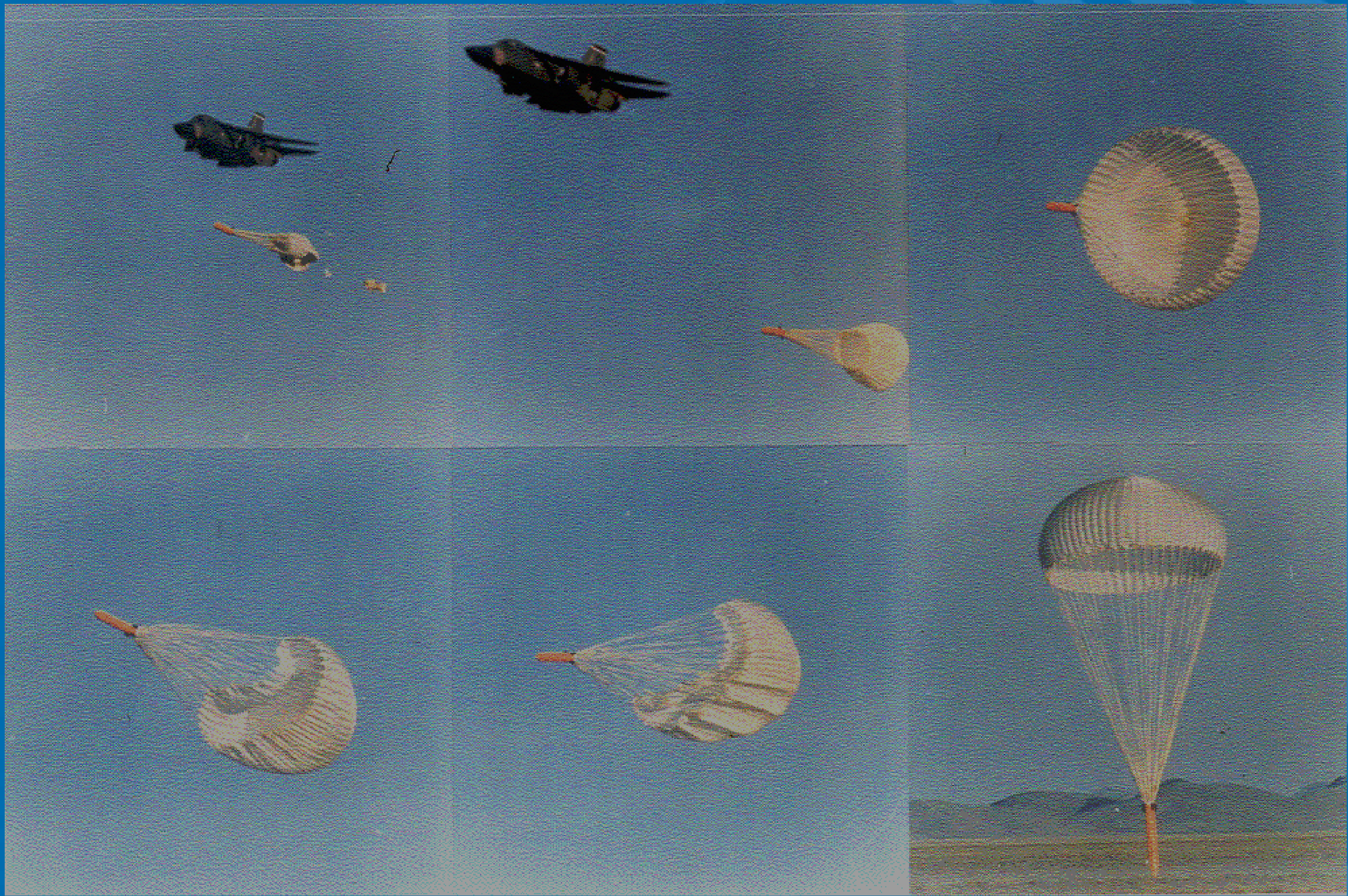
Example of Wake Re-contact



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Definitions (continued)

- **Fullness** - the addition of material in an area to reduce the stresses in the material either by reducing the radius of curvature on a pressure loaded member or by directing load elsewhere in a tension member.
- **Staging** - Event where a parachute (typically a drogue parachute) is released from the payload. Most often another parachute is deployed shortly thereafter.
- **Reefing** - a process by which the canopy is restricted from taking its full open shape and used to tailor the drag profile and hence load history produced by the parachute. (Term derived from a similar process used on sails on boats.)

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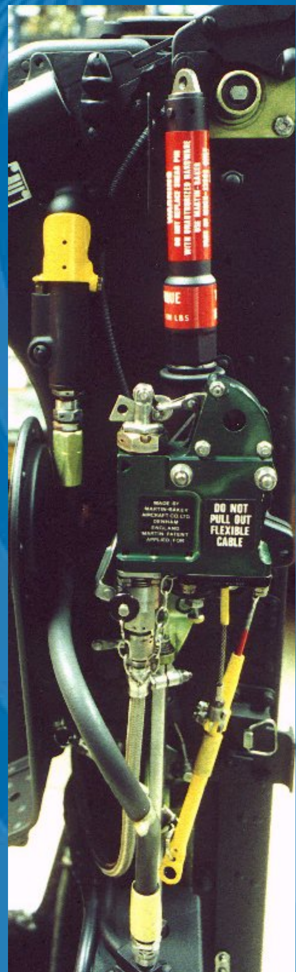
Definitions (continued)

- **Drogue Gun** - a deployment device used to fire a projectile at high velocities from the payload. A riser connecting the projectile to a parachute forces the deployment to begin.
- **Tractor Rocket** - a deployment device used to drag the parachute system out of the payload and deploy it into the airstream.



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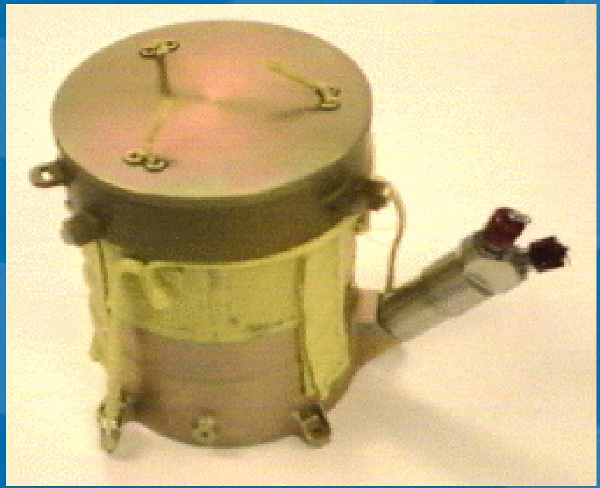
Definitions (continued)

- **Reefing Cutter** - an ordinance device used to release a parachute from a reefed state at the desired time.
- **Mortar** - a deployment device used to eject a packed parachute from the payload as one mass thereby beginning the deployment process.



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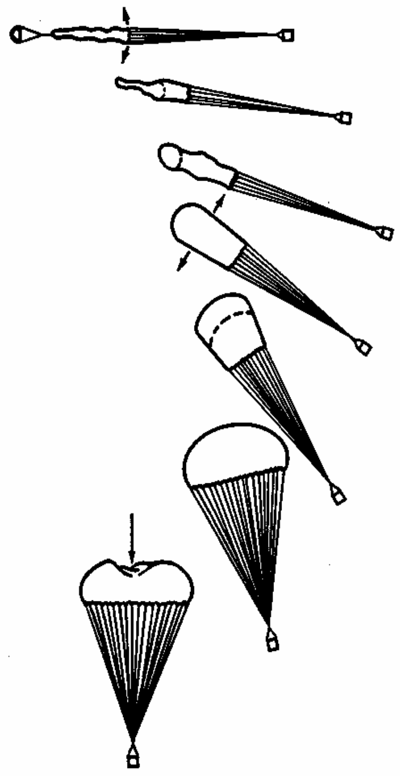
Canopy Inflation Process



(a) OPENING OF CANOPY MOUTH

(b) AIR MASS MOVES ALONG CANOPY

(c) AIR MASS REACHES CROWN OF CANOPY

(d) INFLUX OF AIR EXPANDS CROWN (TYPICAL REEFED INFLATION SHAPE)

(e) EXPANSION OF CROWN RESISTED BY STRUCTURAL TENSION AND INERTIA

(f) CANOPY REACHES FIRST FULLY INFLATED STAGE

(g) SKIRT OVER–INFLATED, CROWN DEPRESSED BY MOMENTUM OF SURROUNDING AIR MASS

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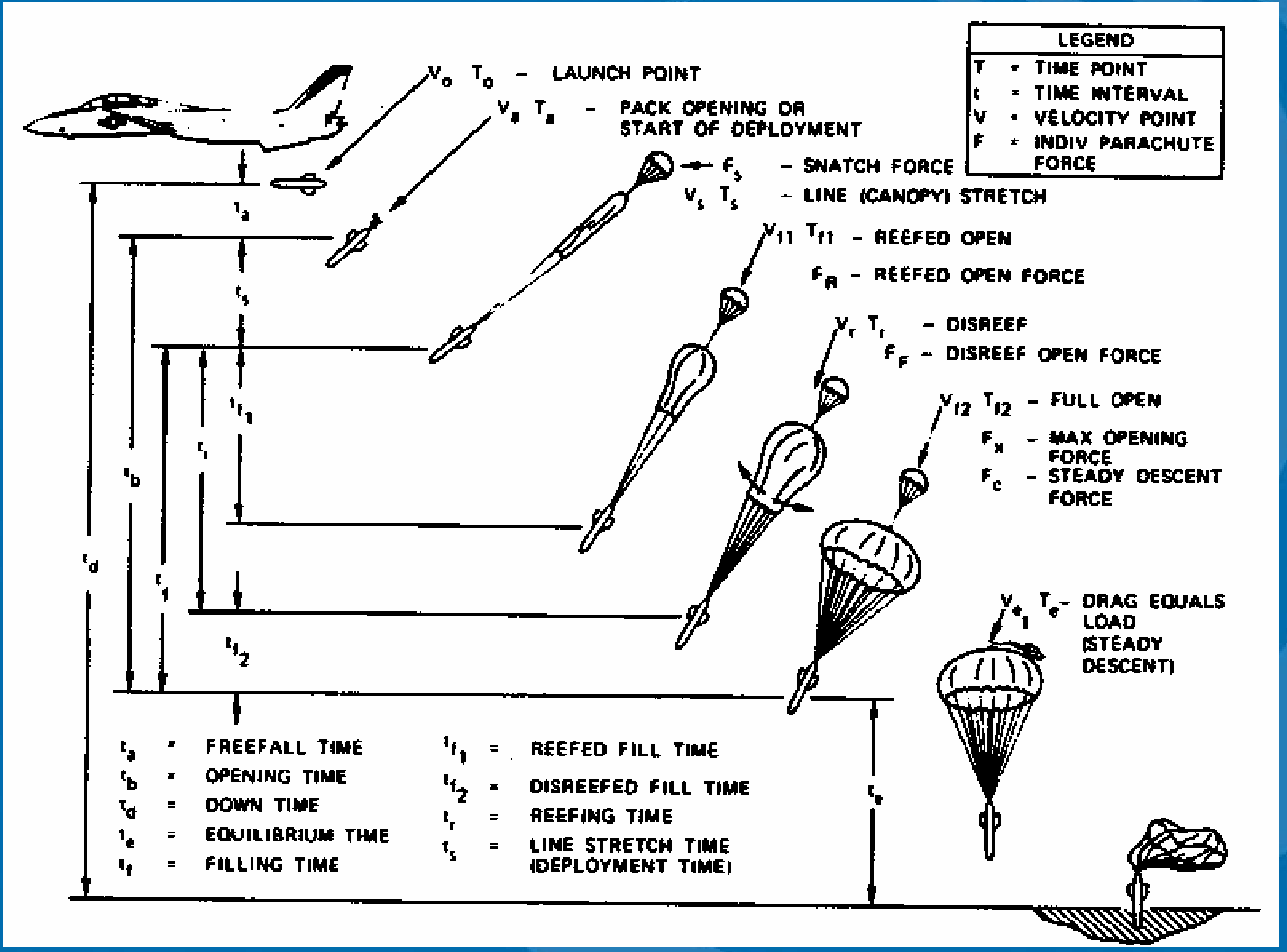
Inflation Sequence Nomenclature



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Drag Area ($C_D S$)

- Product of a drag coefficient (C_D) and a reference area (S)
- Dimensions are ft^2, m^2, acres, etc.
- Characterizes the drag properties of the parachute
- With gravity, air density and vehicle velocity determines the trajectory of a parachute retarded vehicle
- Can be shown as $C_D S$, $C_{D_O} S_O$, $(C_D S)_O$

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Where do I get $C_D S$?

- **Calculation**
  - Drag coefficient - from a manual, empirical data, or from prior experience
  - Area - Typically that necessary to meet requirements

OR

- **Measurement**
  - Matching theoretical trajectory with experimental data

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Drag Areas / Coefficients

- S_O nominal area - is defined as the surface area of the canopy including the vent and any other openings in canopy.
- D_O nominal diameter - is defined as the diameter of a circle whose area is S_O:

$$D_O = \sqrt{\frac{4S_O}{\pi}}$$

- S_P projected area - is defined as the projected frontal area of a parachute in its inflated shape.
- D_P – projected diameter is defined as the diameter of a circle whose area is S_P.
- D_C is defined as the “constructed diameter” of the parachute (typically the diameter at the skirt).

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D_C versus D_O

- For flat circular parachutes, D_C and D_O are the same.
- For simple construction, non-flat parachutes, it is common to base the C_D on the surface area (S_O).
  - Easier to compare the drag efficiency since, normally, the amount of material in the drag surface is a design constraint (weight and volume).
- Parachutes of complex geometry are generally spoken of solely in terms of D_C.

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Decelerator Types

- Construction
  - Solid
  - Slotted
- Flight Characteristics
  - Ballistic
  - Rotating
  - Maneuverable
- Flight Envelope
  - Subsonic
  - Transonic
  - Supersonic
  - Hypersonic

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Solid Parachutes

TYPE	CONSTRUCTED SHAPE PLAN	CONSTRUCTED SHAPE PROFILE	$\frac{D_c}{D_o}$	INFLATED SHAPE $\frac{D_p}{D_o}$	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
FLAT CIRCULAR	D_c		1.00	0.67 TO 0.70	0.75 TO 0.80	~1.7	±10 TO ±40	DESCENT, OBSOLETE
CONICAL		D_c	0.93 TO 0.95	0.70	0.75 TO 0.90	~1.8	±10 TO ±30	DESCENT, M < 0.5
BICONICAL		D_c	0.90 TO 0.95	0.70	0.75 TO 0.92	~1.8	±10 TO ±30	DESCENT, M < 0.5
TRICONICAL POLYCONICAL		D_c	0.90 TO 0.95	0.70	0.80 TO 0.96	~1.8	±10 TO ±20	DESCENT, M < 0.5
EXTENDED SKIRT 10% FLAT		D_c 0.1 D_c	0.86	0.66 TO 0.70	0.78 TO 0.87	~1.4	±10 TO ±15	DESCENT, M < 0.5
EXTENDED SKIRT 14.3% FULL		D_c 0.143 D_c	0.81 TO 0.85	0.66 TO 0.70	0.75 TO 0.90	~1.4	±10 TO ±15	DESCENT, M < 0.5

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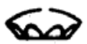
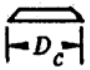
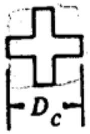
Solid Parachutes (continued)

TYPE	CONSTRUCTED SHAPE PLAN	PROFILE	$\frac{D_c}{D_o}$	INFLATED SHAPE $\frac{D_p}{D_o}$	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
HEMISPHERICAL			0.71	0.66	0.62 TO 0.77	~1.6	±10 TO ±15	DESCENT, $M < 0.5$, OBSOLETE
GUIDE SURFACE (RIBBED)			0.63	0.62	0.28 TO 0.42	~1.2	0 TO ±2	STABILIZATION, DROGUE, $0.1 < M < 1.5$
GUIDE SURFACE (RIBLESS)			0.66	0.63	0.30 TO 0.34	~1.4	0 TO ±3	PILOT, DROGUE, $0.1 < M < 1.5$
ANNULAR			1.04	0.94	0.85 TO 0.95	~1.4	<±6	DESCENT, $M < 0.5$
CROSS			1.15 TO 1.19	0.66 TO 0.72	0.60 TO 0.85	1.1 TO 1.2	0 TO ±3	DESCENT, DECELERATION

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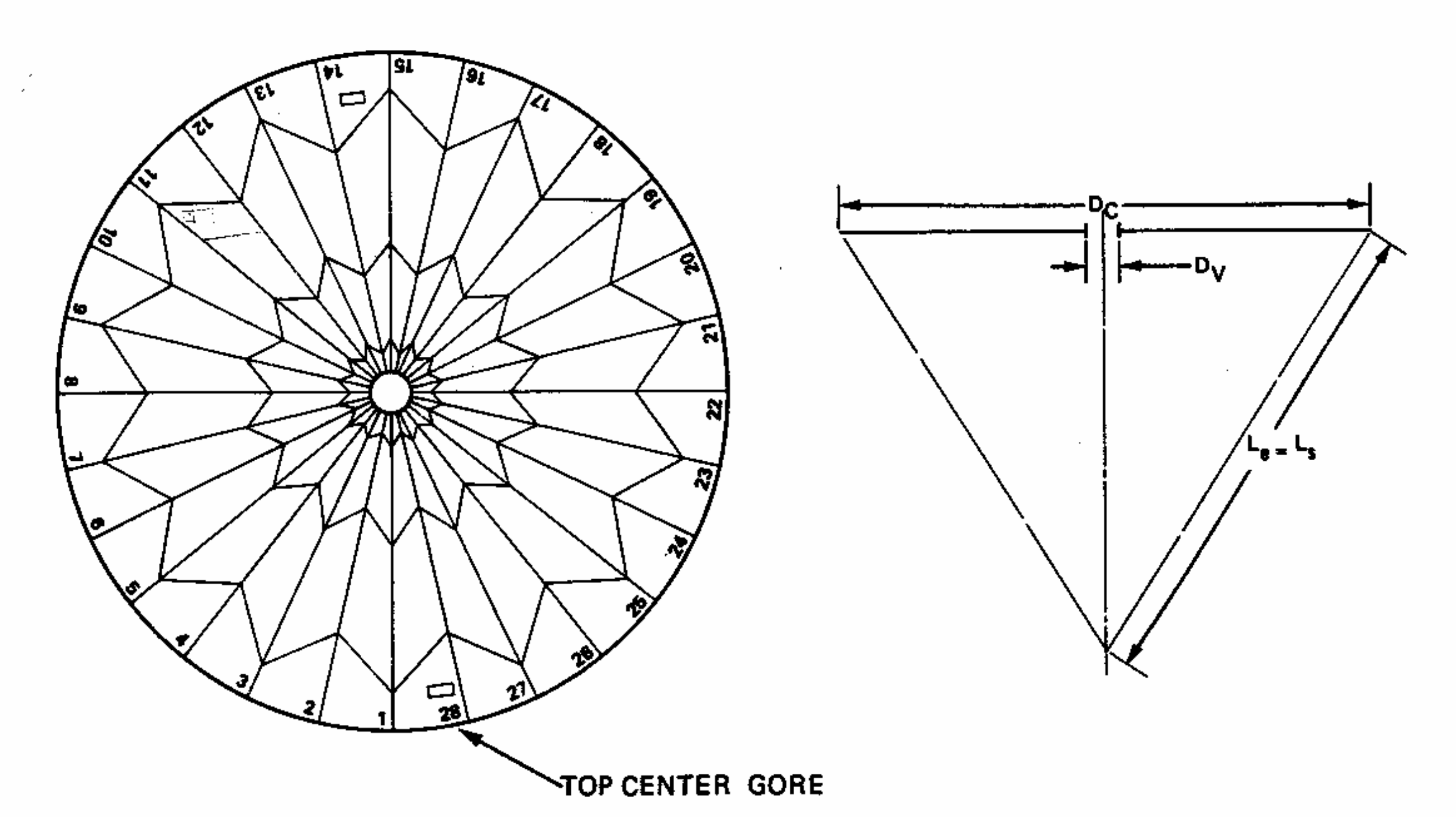
Solid Parachute - Flat Circular



(Bias Construction shown)

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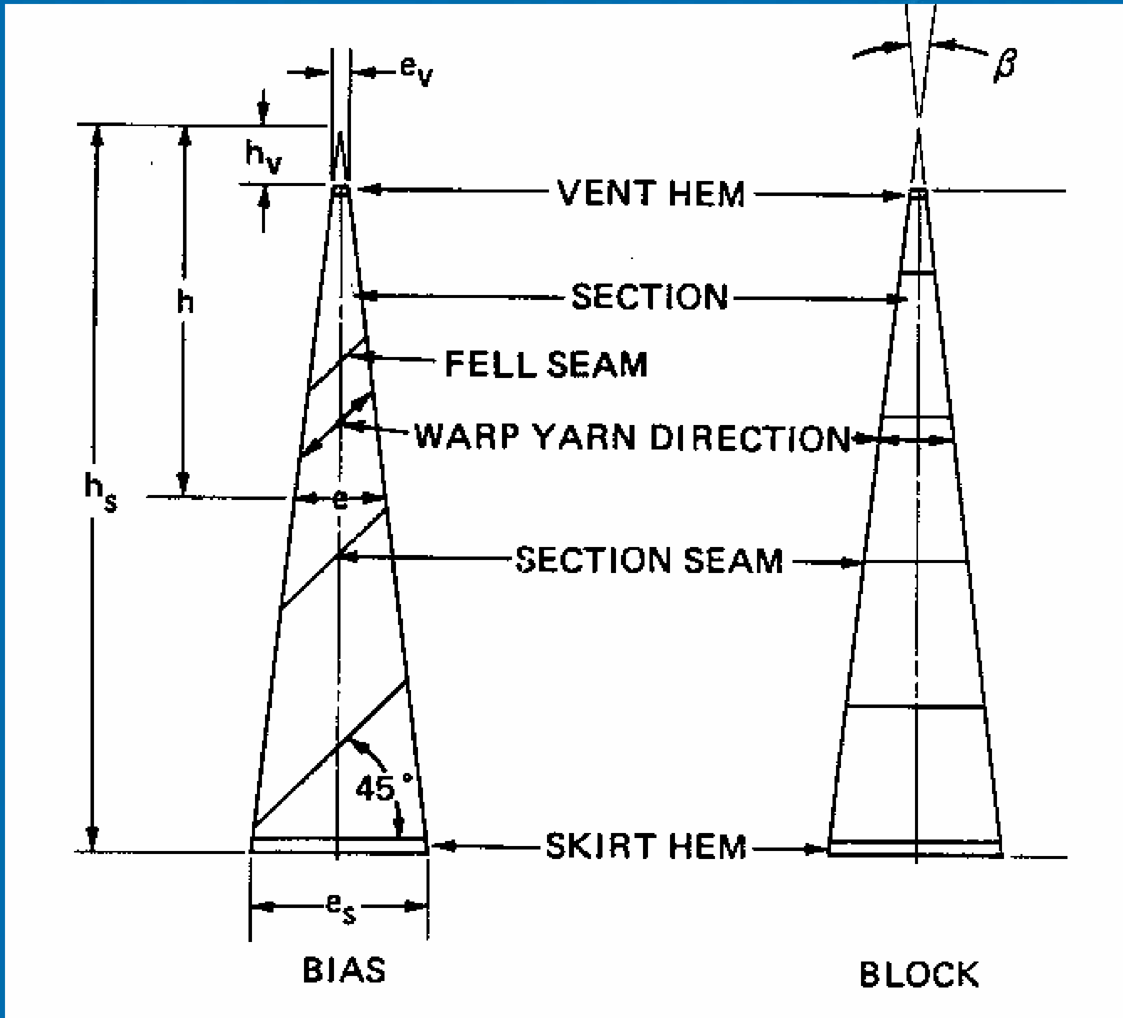
Solid Parachute - Flat Circular



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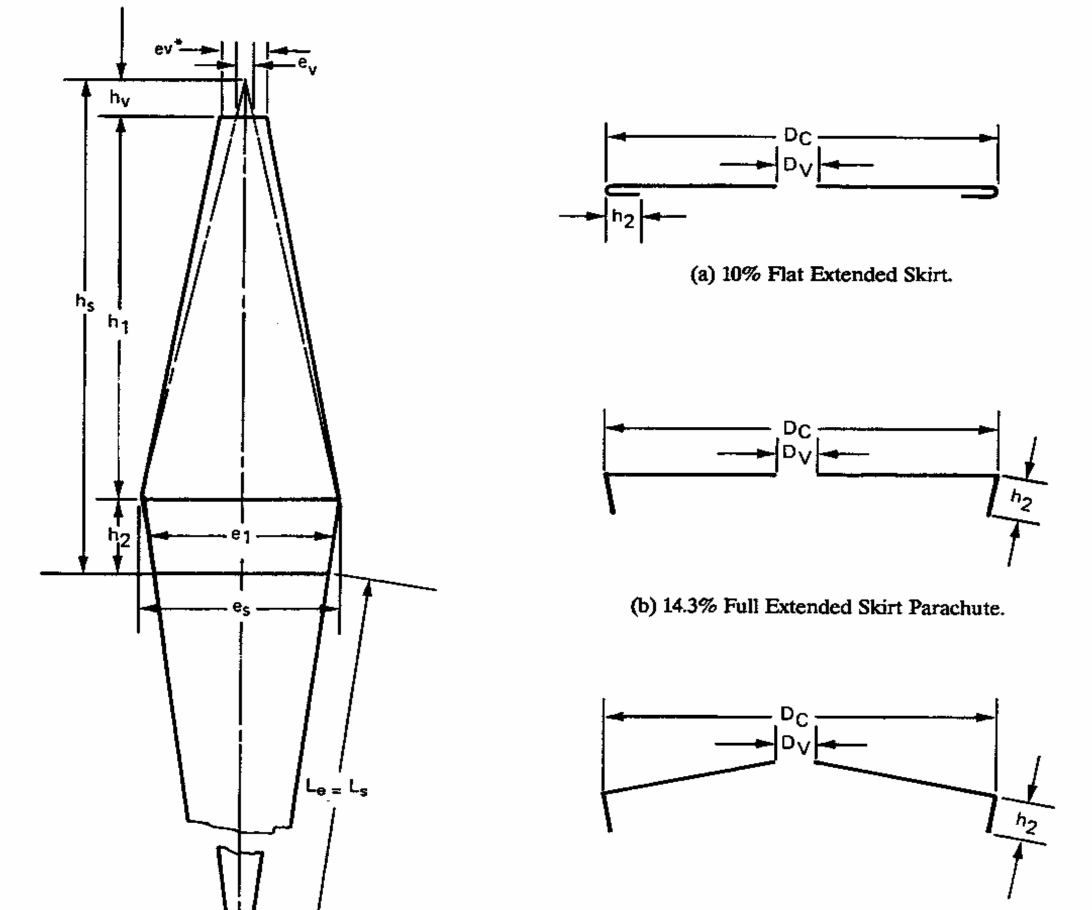
Solid Parachute - Extended Skirt

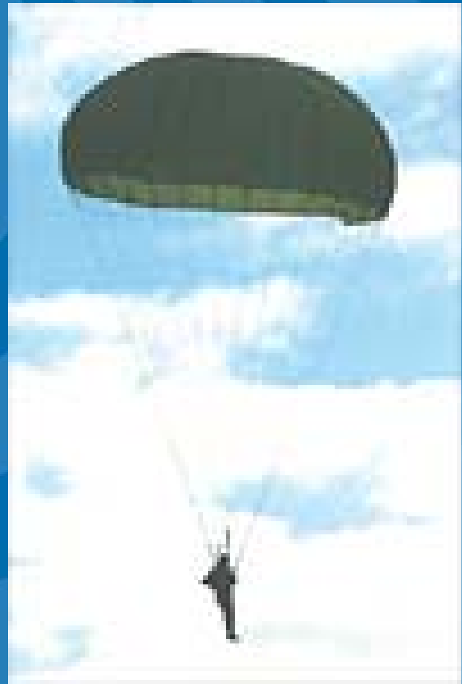


(a) 10% Flat Extended Skirt.

(b) 14.3% Full Extended Skirt Parachute.

(c) 14.3% Conical Full Extended Skirt Parachute.

L_s = Length of suspension lines
L_e = Effective length of suspension lines



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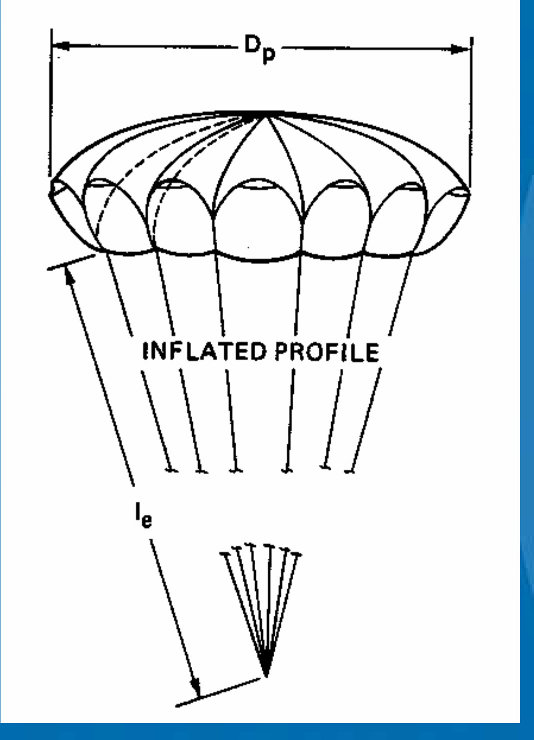
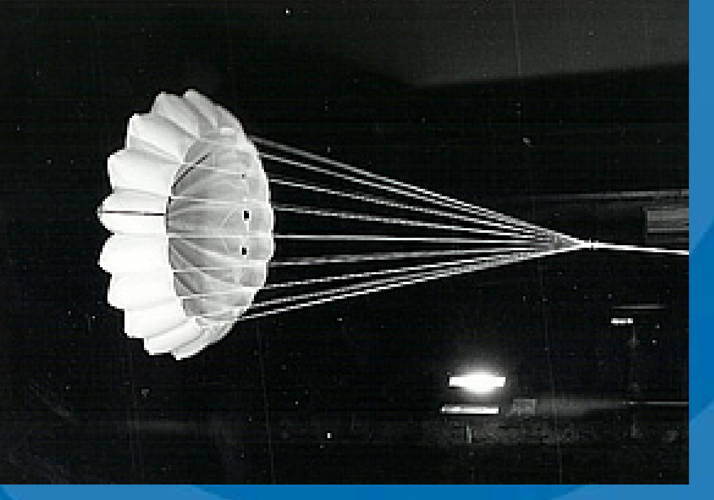
Solid Parachute - Guide Surface

Ribless





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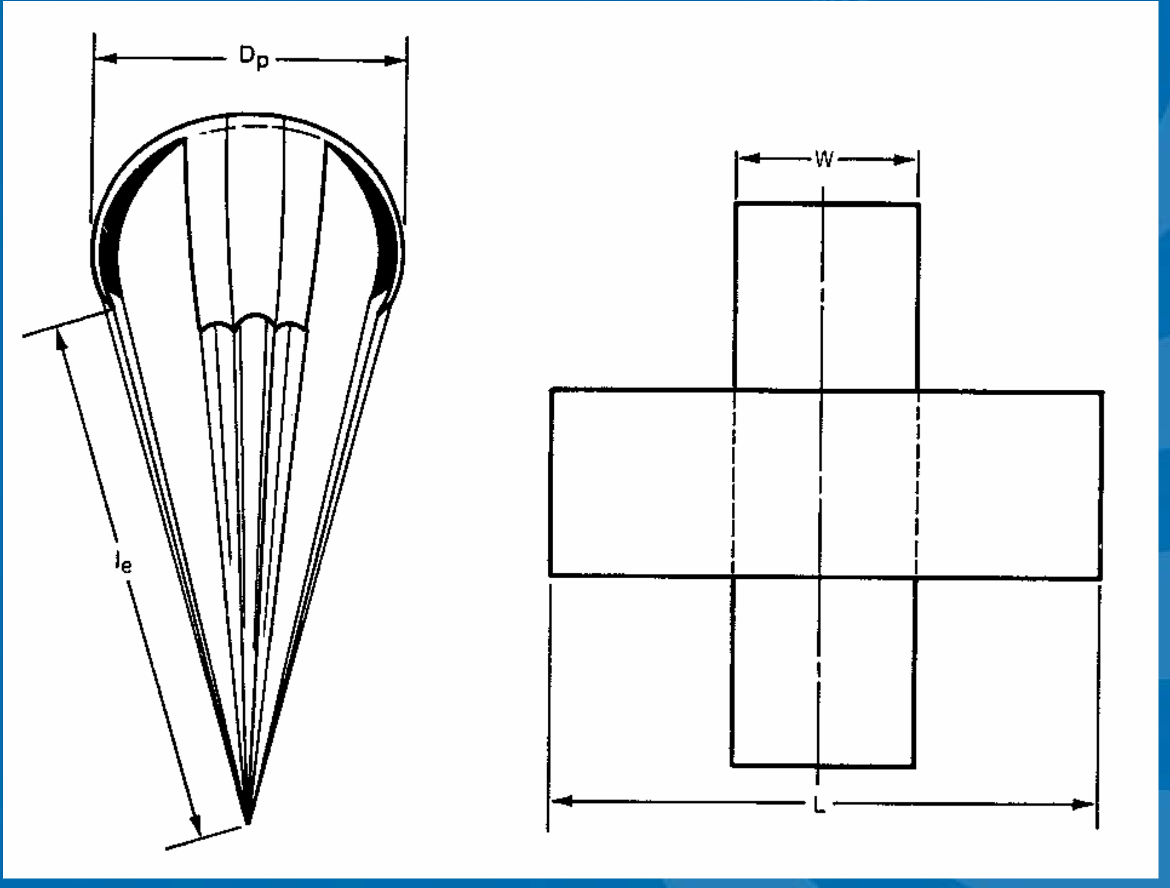
Solid Parachute - Cross



Slotted Parachutes

TYPE	CONSTRUCTED SHAPE: PLAN	CONSTRUCTED SHAPE: PROFILE	CONSTRUCTED SHAPE: $\frac{D_c}{D_o}$	INFLATED SHAPE $\frac{D_p}{D_o}$	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
FLAT (FIST) RIBBON	D_c		1.00	0.67	0.45 TO 0.50	~1.05	0 TO ±3	DROGUE, DESCENT, DECLERATION, OBSOLETE
CONICAL RIBBON		D_c	0.95 TO 0.97	0.70	0.50 TO 0.55	~1.05	0 TO ±3	DESCENT, DECELERATION, $0.1 < M < 2.0$
CONICAL RIBBON (VARIED POROSITY)		D_c	0.97	0.70	0.55 TO 0.60	1.05 TO 1.30	0 TO ±3	DROGUE, DESCENT, DECELERATION, $0.1 < M < 2.0$
RIBBON [1] (HEMISFLO)		D_c	0.62	0.62	0.30 [1] TO 0.46	1.00 TO 1.30	±2	SUPERSONIC, DROGUE, $1.0 < M < 3.0$
RINGSLOT		D_c	1.00	0.67 TO 0.70	0.56 TO 0.65	~1.05	0 TO ±5	EXTRACTION, DECELERATION, $0.1 < M < 0.9$
RINGSAIL		D_c	0.84	0.69	0.75 TO 0.85	~1.10	±5 TO ±10	DESCENT, $M < 0.5$
DISC–GAP–BAND		D_c	0.73	0.65	0.52 TO 0.58	~1.30	±10 TO ±15	DESCENT, $M < 0.5$

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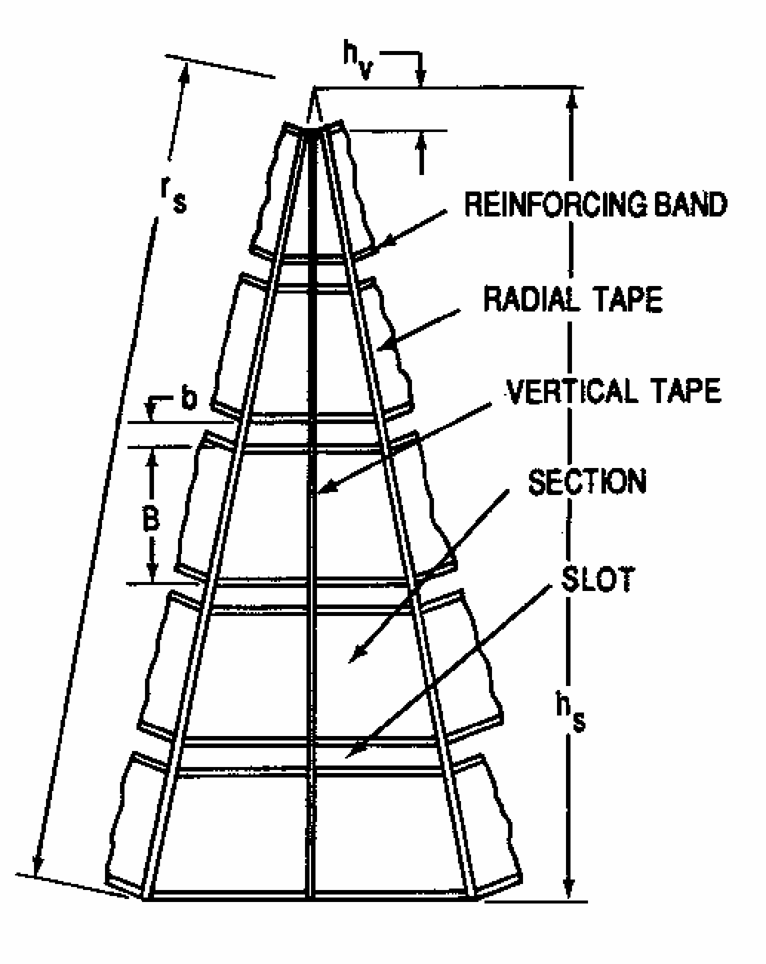
Slotted Parachutes - Ringslot



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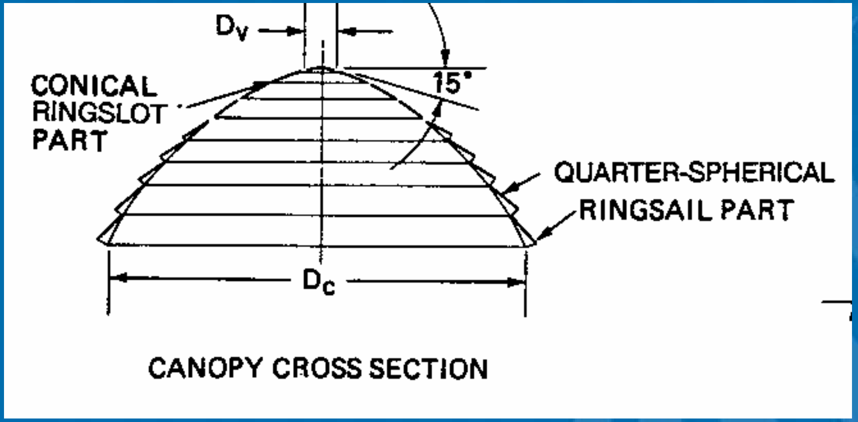
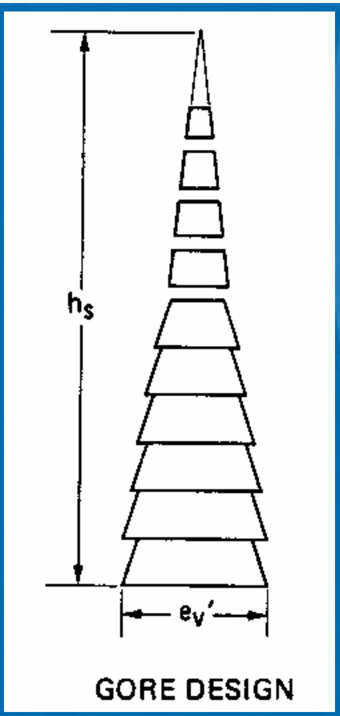
Slotted Parachutes - Ringsail





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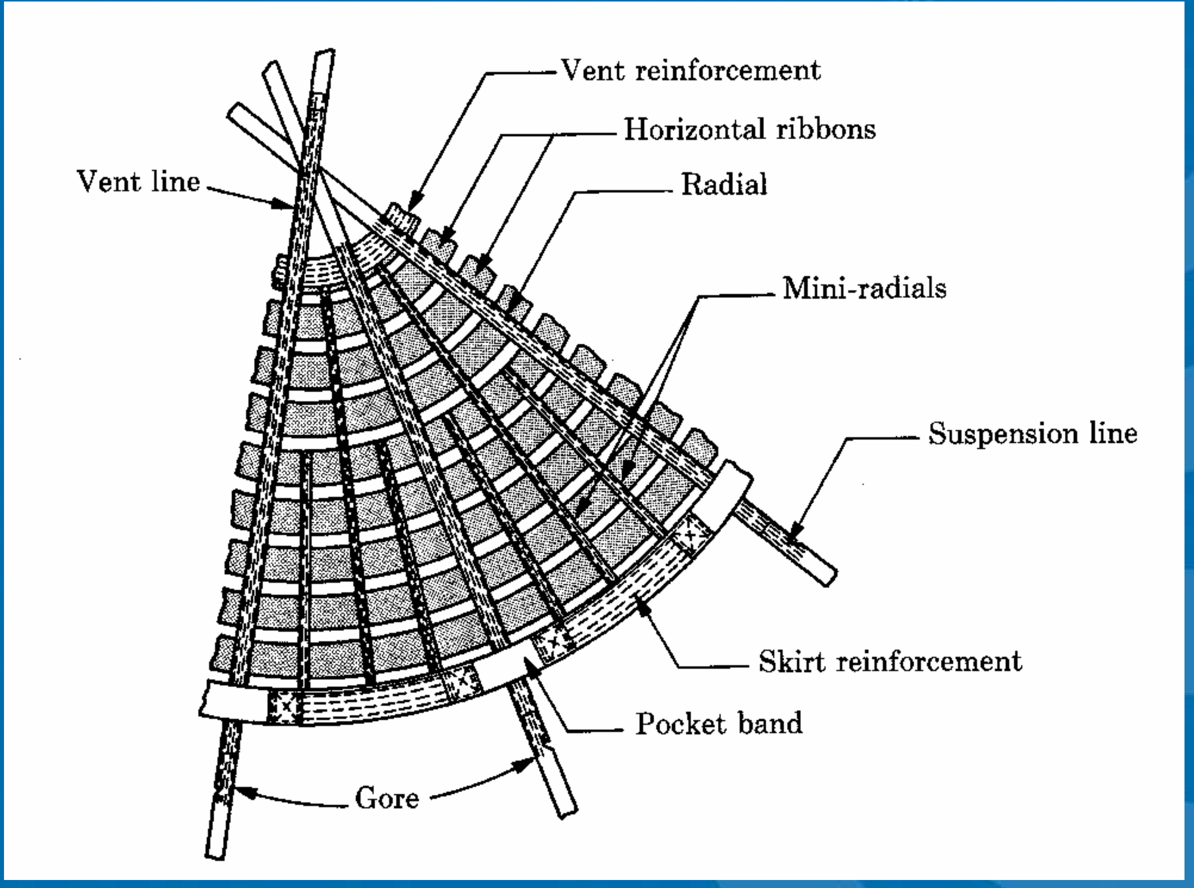
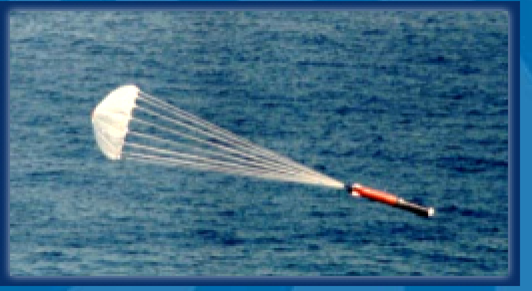
Slotted Parachutes - Ribbon





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Canopy Shapes

- Flat
- Conical
- Polyconical
- Hemispherical
- Quarter-spherical
- Disk-Gap-Band (DGB)

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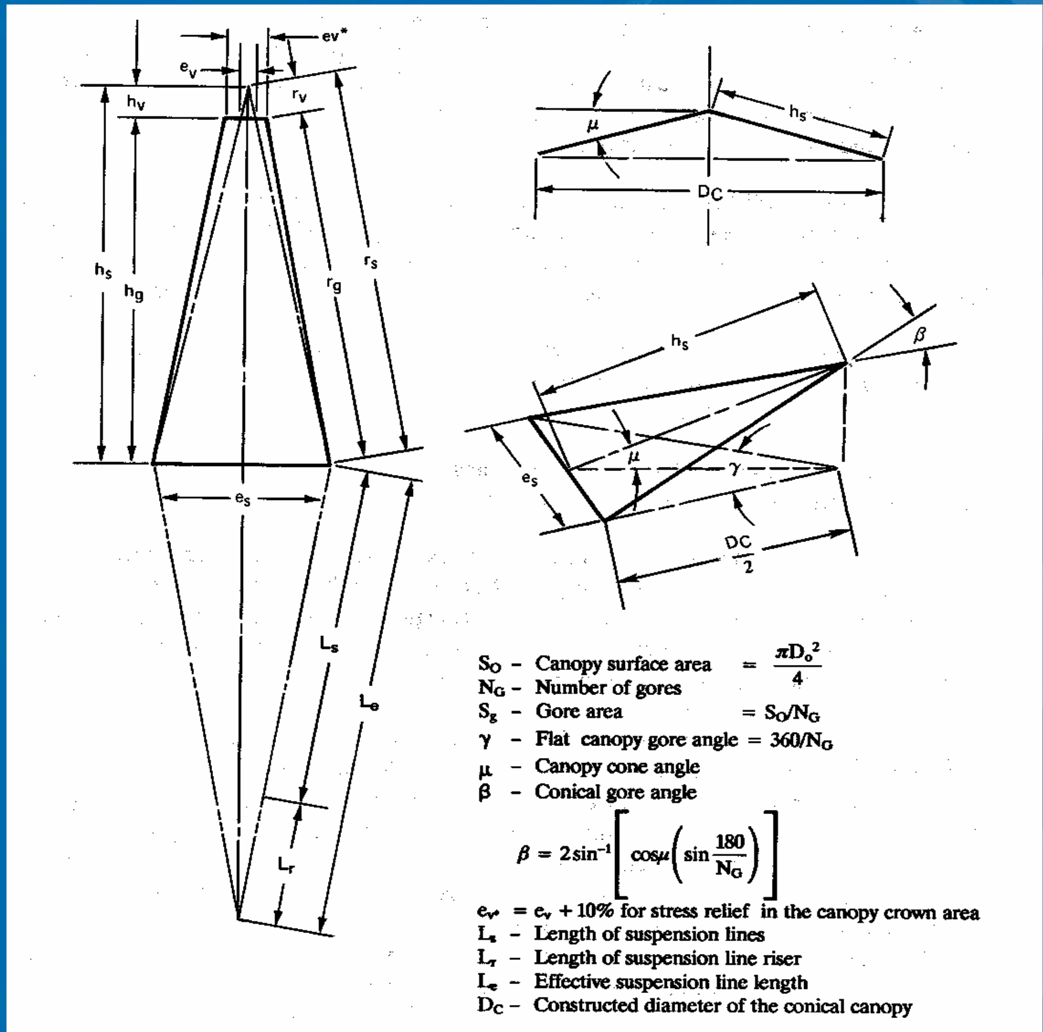
Flat vs. Conical



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D_C versus D_O

- For conical parachutes $$D_C = D_O \sqrt{\cos \mu} \quad \left(\mu = \text{cone} \, \frac{1}{2} \angle \right)$$
- For 10˚ conical parachute:
  
  - $D_O = 1.008 \, D_C$
- For 20˚ conical parachute:
  
  - $D_O = 1.03 \, D_C$
- For 30˚ conical parachute:
  
  - $D_O = 1.07 \, D_C$

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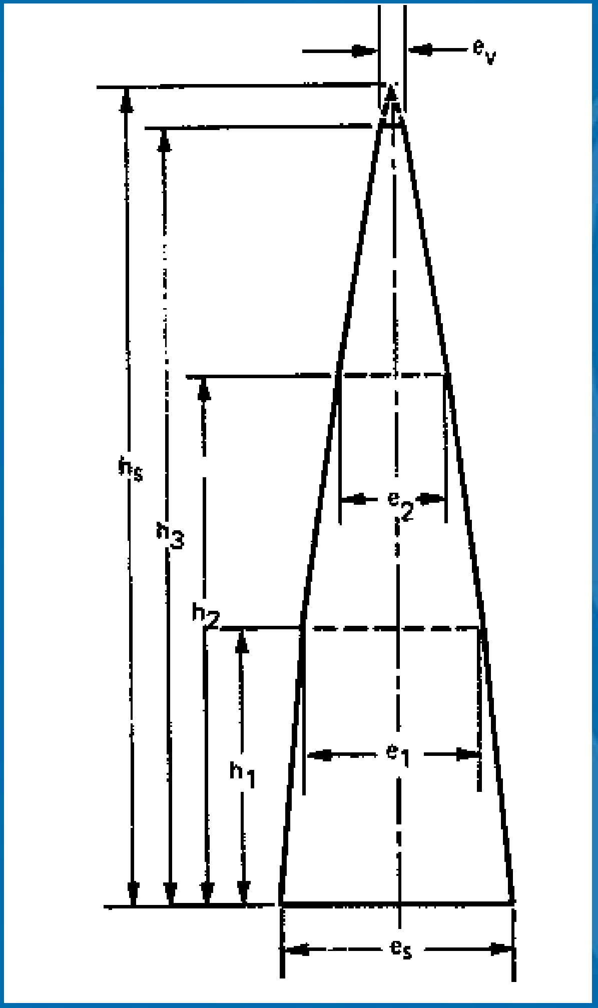
Polyconical



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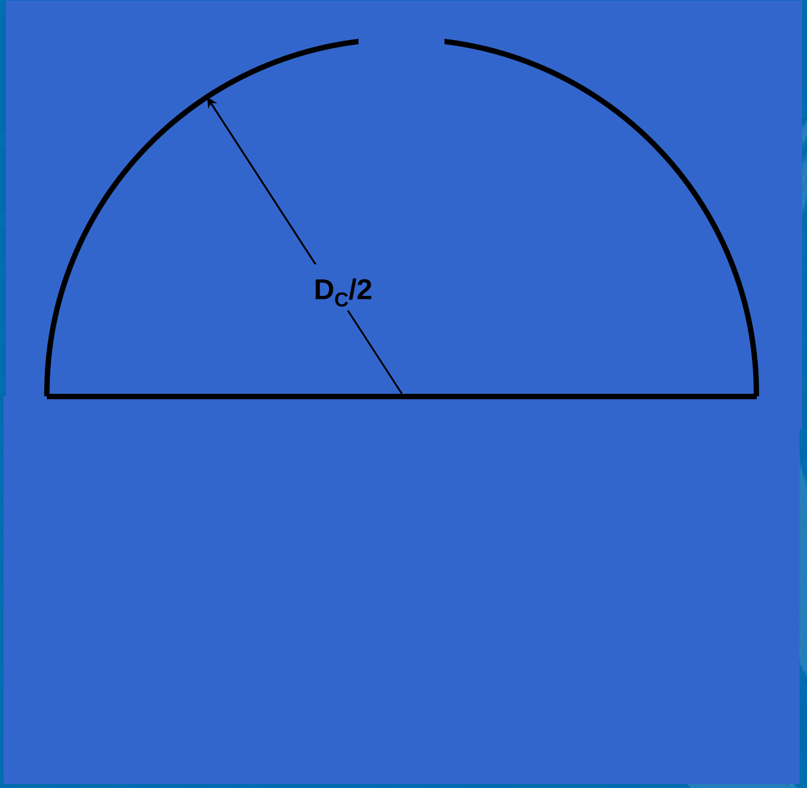
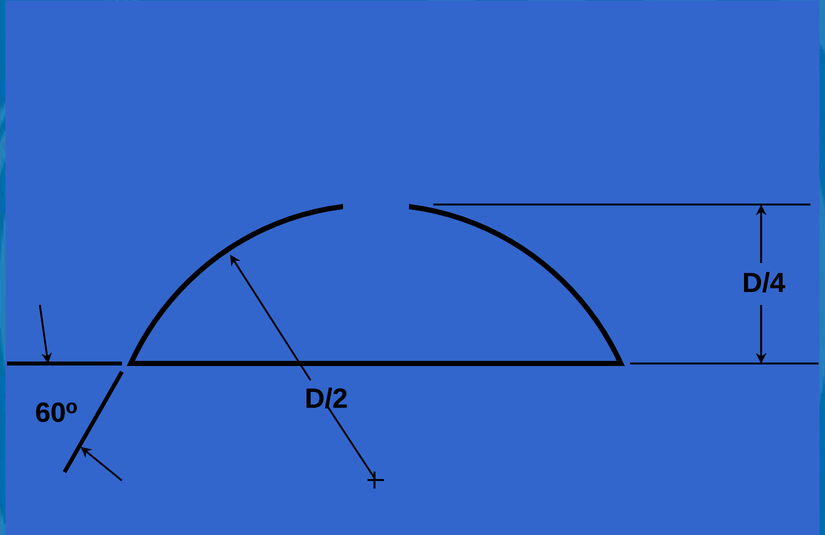
Hemispherical / Quarter spherical





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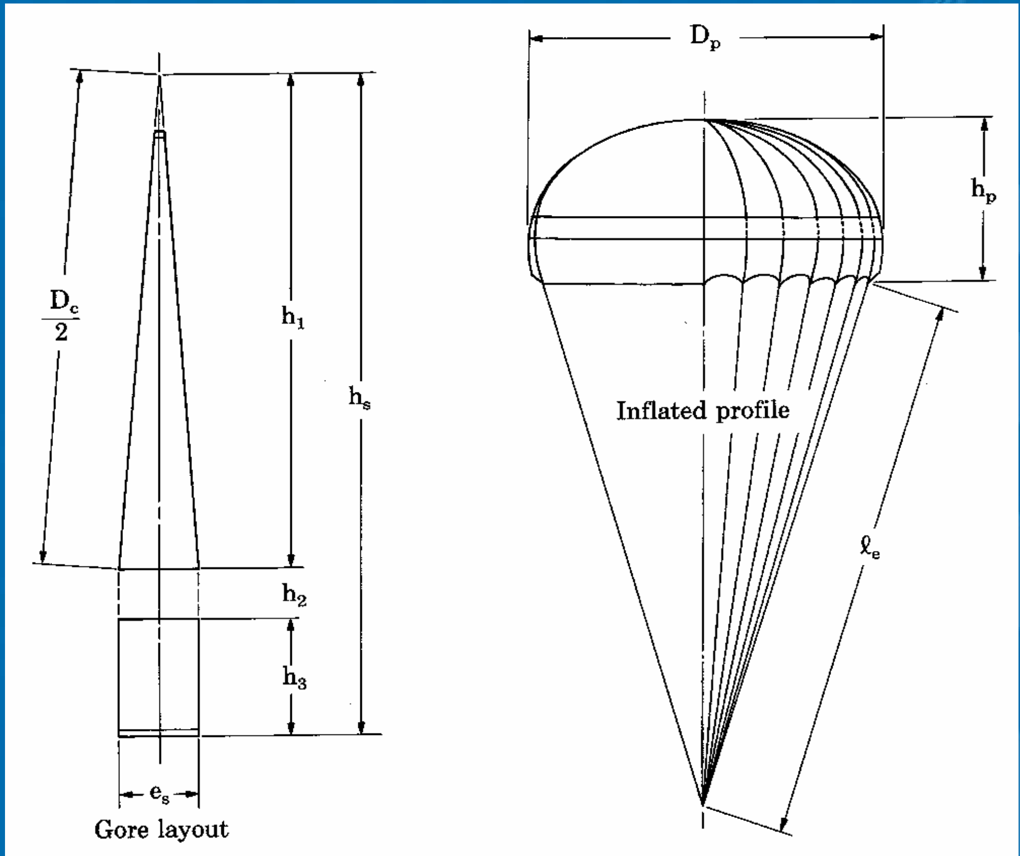
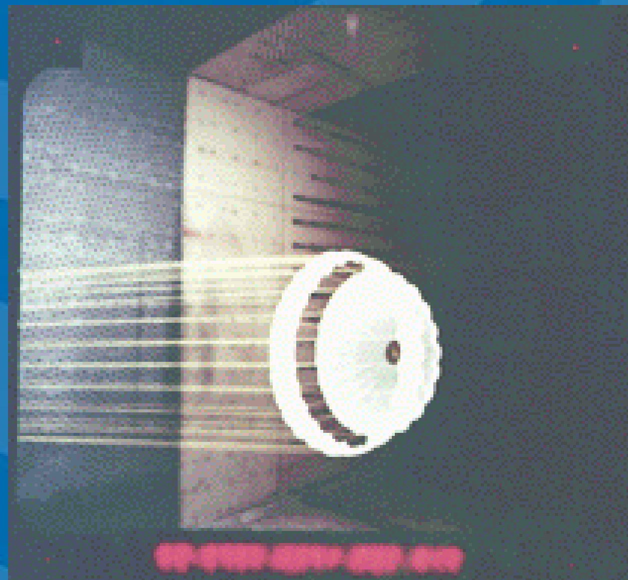
Disk/Gap/Band (DGB)





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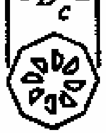
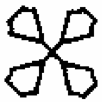
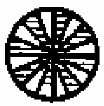
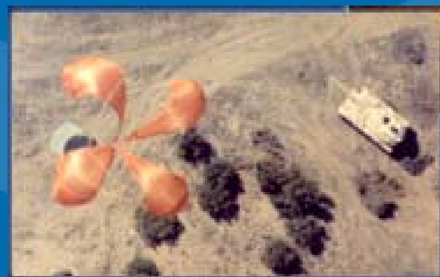
Rotating Parachutes

TYPE	CONSTRUCTED SHAPE PLAN	PROFILE	$\frac{D_c}{D_o}$	INFLATED SHAPE $\frac{D_p}{D_o}$	DRAG COEF C_{D_o} RANGE	OPENING FORCE COEF C_X (INF MASS)	AVERAGE ANGLE OF OSCILLATION, DEGREES	GENERAL APPLICATION
ROTAFOIL	D_c 		1.0	~0.90	0.85 TO 0.99	1.05	0 TO ±2	DROGUE, $D_o < 7$
VORTEX RING			1.9	N/A	1.5 TO 1.8	1.1 TO 1.2	0 TO ±2	DESCENT, SMALL D_o
SANDIA RFD			1.0	~0.9	1.25	1.1	0 TO ±2	DROGUE



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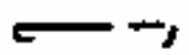
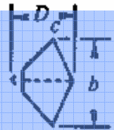
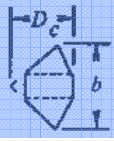
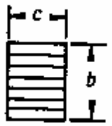
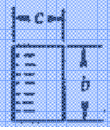
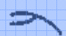
Maneuverable Parachutes

TYPE	CONSTRUCTED SHAPE PLAN	CONSTRUCTED SHAPE PROFILE	AREA RATIO S_w / S_o	AERODYNAMIC FORCE COEF C_R RANGE	GLIDE RATIO $(L/D)_{MAX}$	GENERAL APPLICATION
TOJO, TU SLOTS, ETC			1.0	0.85 TO 0.90	0.5 TO 0.7	DESCENT
LeMOIGNE (PARACOMMANDER)			1.0	0.90 TO 1.00	1.1	DESCENT
PARAWING (SINGLE KEEL)			1.0	0.90 TO 1.10	2.0 TO 2.5	DESCENT
PARAWING (TWIN KEEL)			1.0	1.00 TO 1.10	2.8[1] TO 3.0	DESCENT
PARAFOIL			0.27	0.75 TO 0.85	2.8[1] TO 3.5	DESCENT
SAILWING			0.80 TO 0.90	N/A	2.8[1] TO 3.5	DESCENT
VOLPLANE			0.60	N/A	2.0[1] TO 3.0	DESCENT

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Manoeuvrable Chutes

- Derry Slot
- T & U Slot
- TOJO
- All use some sort of slots and holes to direct the parachute in specific direction.
- Glide Ratios 0.5 - 0.7

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Man. Chutes - High Glide (Cont.)

- Parafoil

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Supersonic Decelerators

- Conical Ribbon
- Hemisflo
- Supersonic-X
- Hyperflo
- Ballute

- Will be discussed in supersonic parachutes lecture

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Reference Material

- T. W. Knacke, Parachute Recovery Systems Design Manual, NWC TP6575, Naval Weapons Center, China Lake, CA, Distributed by Para-Publishing, P.O. Box 4232, Santa Barbara, CA 91340-4232.
- D. J. Cockrell, The Aerodynamics of Parachutes, AGARDograph No. 6295.
- R. C. Maydew and C. W. Peterson, Design and Testing of High-Performance Parachutes, AGARDograph 319.
- Recovery Systems Design Guide, AFFDL-TR-78-151, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio

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Reference Material (continued)

- U.S. Air Force Reports (especially from the old AFFDRC at Wright Field).
- AIAA Aerodynamic Decelerator Systems Technology Conference Proceedings and Seminar Lecture Notes (Nos. 1-14).
- University of Minnesota Parachute Systems Technology Short Courses.
- Survival and Flight Equipment (SAFE) Symposia.
- Parachute Industry Association (PIA) Symposia.
- D. Poynter, “The Parachute Manual, Vols. I & II,” Para-Publishing, P.O. Box 4232, Santa Barbara, CA 91340-4232.

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